EXTENDING REMOTE PATIENT MONITORING WITH MOBILE REAL TIME CLINICAL DECISION SUPPORT

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Abstract

Large scale implementation of telemedicine services such as telemonitoring and teletreatment will generate huge amounts of clinical data. Even small amounts of data from continuous patient monitoring cannot be scrutinised in real time and round the clock by health professionals. In future huge volumes of such data will have to be routinely screened by intelligent software systems. We investigate how to make m-health systems for ambulatory care more intelligent by applying a Decision Support approach in the analysis and interpretation of biosignal data and to support adherence to evidence-based best practice such as is expressed in treatment protocols and clinical practice guidelines. The resulting Clinical Decision Support Systems must be able to accept and interpret real time streaming biosignals and context data as well as the patient's (relatively less dynamic) clinical and administrative data. In this position paper we describe the telemonitoring/teletreatment system developed at the University of Twente, based on Body Area Network (BAN) technology, and present our vision of how BAN-based telemedicine services can be enhanced by incorporating mobile real time Clinical Decision Support. We believe that the main innovative aspects of the vision relate to the implementation of decision support on a mobile platform; incorporation of real time input and analysis of streaming biosignals into the inferencing process; implementation of decision support in a distributed system; and the consequent challenges such as maintenance of consistency of knowledge, state and beliefs across a distributed environment.

1 Introduction

Telemonitoring and teletreatment services are emerging as frontline telemedicine applications of Body Area Network (BAN) technology. The patient wears a BAN equipped with a set of wearable devices needed for the particular clinical application. For telemonitoring services, the BAN incorporates a set of body worn sensors and transmits captured biosignals to a remote healthcare location where they can be viewed by clinicians. Analysis of biosignals may be also be performed locally on the BAN and/or remotely, at the healthcare organization, for example, or at a third party service provider. Telemonitoring may be augmented with teletreatment; inclusion of a local (micro) feedback loop enables automated local feedback to the patient, and possibly intervention, at the BAN; a macro feedback loop enables a remote system and/or remote clinician to give advice, support and, if necessary, clinician initiated or (semi-)automated intervention. Depending on the nature of the intervention, automated or semi-automated intervention may involve actuators as well as sensors in the BAN, for example to control automated medication delivery. Biosignals will be preprocessed before being transmitted by the BAN to a server known at the BAN Back End System, from where they can be retrieved in some form by various health professionals at the clinical back end by means of an m-health portal. Figure 1 illustrates the telemonitoring and teletreatment concept.

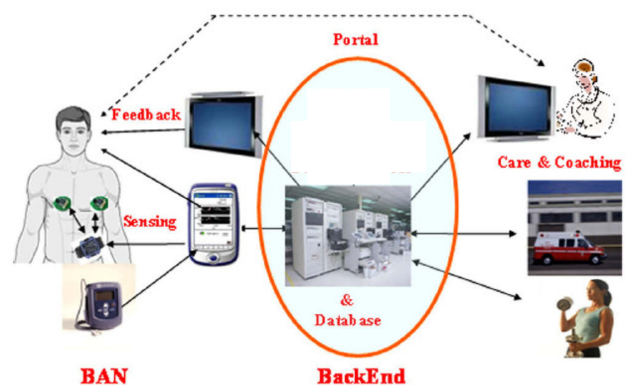

Fig. 1.Telemonitoring/teletreatment (Source: [10])

We are beginning to investigate in what circumstances it is feasible and useful to apply clinical decision support technology to the problem of analysis and interpretation of BAN data and to aid clinicians and patients in decision making and in adherence to best practice. The intention is to build on our current mobile monitoring systems and develop more intelligent, evidence-based monitoring and treatment applications for home-based care, to better support self-care by patients and remote care by health professionals.

In section 2 we describe the health BAN system. In section 3 Clinical Decision Support is briefly introduced. Our initial ideas about the incorporation of Decision Support are outlined in section 4 and a summary of the innovative features together with some discussion points are presented in section 5.

2 The Mobile Monitoring and Treatment System

The MobiHealth Body Area Network (BAN) [1-4] developed at Twente consists of a set of body-worn devices, which may include one or more sensors (and possibly actuators and other devices) and a processing and communication platform (a mobile phone or PDA). A generic architecture for Body Area Networks (BANs) and a supporting m-health service platform (MSP) have been developed. Based on the generic architecture, a series of specialised BANs together with condition specific software applications have been developed since 2002. Telemonitoring and teletreatment applications have been trialled on different patient groups over the course of a number of collaborative projects (IST MobiHealth, IST XMotion, eTEN HealthService24, Freeband Awareness, eTEN Myotel, FOVEA, U-CARE, CLEAR and COPD.com). Patient trials to date include cardiac monitoring, pregnancy monitoring, trauma care, mental health, COPD, epilepsy and chronic pain management. Figures 2 and 3 show two variants of the MobiHealth BAN.

Fig. 2. Epilepsy monitoring BAN

Figure 2 shows the components of one example of a telemonitoring BAN, the epilepsy BAN developed to detect seizures by means of analysis of biosignals and context data. Figure 3 shows an example of a telemonitoring and teletreatment BAN designed to monitor neck and shoulder pain and give multimodal feedback to the patient to encourage relaxation of the trapezius muscles when a certain relaxation threshold called Relative Rest Time is exceeded. More details of these applications can be found in [3].

Sensors which have been integrated into the MobiHealth BAN to date are: electrodes for measuring 3, 4 and 9 channel ECG and surface EMG, pulse oximeter, respiration sensor, temperature sensor and activity sensors (step-counter, 3D accelerometer). Apart from sensors, other BAN devices which have been integrated are an actuator providing tactile feedback (vibration), GPS positioning devices and alarm buttons.

Fig.3 Chronic pain monitoring and treatment BAN

PDA screen © MobiHealth BV

Captured biosignals undergo a series of processes starting with low level signal processing and ending with high level clinical analysis and interpretation to various levels of abstraction in order, for example, to detect medical emergencies or adverse trends. Some basic signal processing (eg. ADC, signal conditioning and filtering) always occurs in the sensor system (at the sensor front end) and higher level processing may be implemented locally on the BAN or at the Back End.

For certain clinical interpretation tasks, such as detecting when certain pre-specified thresholds are exceeded, an algorithmic approach suffices. Other interpretation tasks require a more sophisticated approach, involving fusion and analysis of data from multiple sensors together with context data in order to analyse and interpret BAN data [3, 5-6]. This is one of a number of tasks where a knowledge based approach can be usefully applied.

3 Clinical Decision Support

Medical knowledge is very often probabilistic in nature, bringing a requirement for reasoning with uncertainty; furthermore in many cases medical processes, such as diagnostic and assessment processes, are characterized by the need to reason in the face of uncertainty and missing data. Clinical guidelines and other knowledge sources, as well as clinical reasoning, frequently involve qualitative reasoning. These characteristics suggest that a Knowledge Based Systems approach would seem to be appropriate to address some of the challenges of scaling up telemedicine services and improving timely support to clinicians and patients using appropriately filtered knowledge.

Clinical Decision Support (CDS) research arose out of early work by the Artificial Intelligence and Medical Informatics communities and applies a Knowledge Based approach to problems from the medical domain. Early AI systems in medicine focused on diagnosis and treatment proposal and were often referred to as medical Expert Systems. The current view is that CDS is needed to support the entire clinical process.

Following early successes, and very high expectations, there came a shift of emphasis from so called 'Expert Systems' towards Decision Support Systems; instead of emulating (and possibly replacing) the expert, the focus shifted towards supporting the (medical) expert, and indeed other stakeholders, with appropriate knowledge at the time and place of decision making. Two contemporary examples of Clinical Decision Support Systems in use in the Netherlands are the Promedas system and the CARDSS system. Promedas [7] is a diagnostic decision support system utilising Bayesian networks and probabilistic reasoning. It produces differential diagnoses for diseases in the area of internal medicine and suggests the most efficient (laboratory) test to apply to maximally reduce uncertainty. CARDSS [8] addresses a different part of the clinical process by aiding cardiac care teams with adherence to the Dutch national guidelines for cardiac rehabilitation following MI or cardiac surgery. It is used in over 40 Dutch cardiac rehabilitation outpatient clinics. Both systems are intended for use in hospitals by clinicians.

4 Extension of the BAN with CDS

Clinical interpretation of biosignal and context data is one of the tasks where we investigate applying decision support technology. Other possible applications are: to aid the patient with compliance to the treatment regime; to identify medical emergencies and initiate appropriate response; to detect slowly developing adverse trends; and to aid the health professionals with adherence to complex and changing clinical protocols and guidelines.

The addition of Decision Support to the BAN system was proposed in [10] as illustrated in Figure 4.

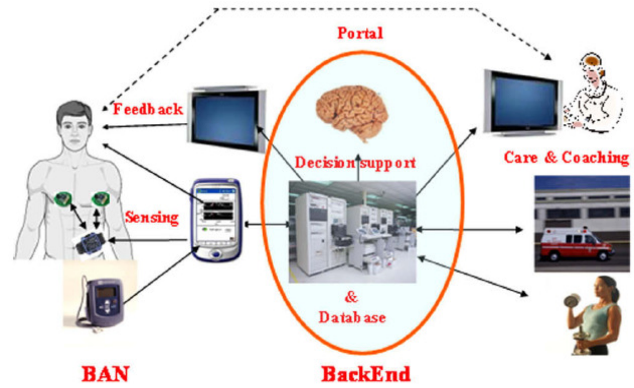

Fig. 4. Extension with CDS (Source: [10])

The concept is elaborated in Figure 5. The CDSS includes the classic KBS components: a domain specific knowledge base containing declarative and procedural knowledge and a reasoning component (sometimes called an inference engine). The inference engine applies the knowledge to a specific case (in this case an individual patient's data) in order to arrive at conclusions. The system should be able to expose its line of reasoning by means of an explanation facility. The first innovation we introduce is that the envisaged system will accept streaming biosignals and context data from a Body Area Network, transmitted real-time over wireless communications links, as well as the normal (relatively) static data which is input to KBSs.

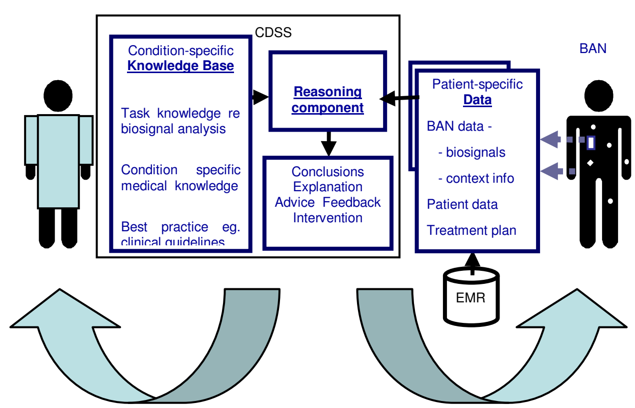

Fig. 5. CDSS with real time biosignal input from BAN

Figure 4 can be read as implying that the Decision Support functions are implemented centrally, eg at the BAN Back End System. Indeed this is one possibility. Another is that the decision support functionality could be distributed end-to-end, with local decision support for the patient implemented on the BAN and local or centrally implemented decision support accessed by the various members of the healthcare team. Hence the second challenge involves implementing distributed decision support. Furthermore the location of knowledge bases and of execution of decision support processes may even be dynamically redistributed during operation to optimize use of network and processing resources, in line with part of our current research on dynamic task allocation as reported in [9].

Further, to have local decision support functionality on the BAN means implementing a sophisticated AI system on a mobile platform (a smart phone or PDA); this is the third challenge. Also following from the vision of a distributed DSS together with the use of mobile platforms, the additional challenge arises of maintaining consistency across the distributed decision support system. This requires mechanisms for harmonizing or synchronizing the views of the different actors using the distributed system, for example ensuring that the local DSS on the patient BAN is reconciled with the health professionals' views, despite the vagaries of wireless communications and the shortcomings inherent in current mobile devices.

5 Discussion

To summarise, we believe that the main innovative aspects of, and the challenges posed by, our proposed use of Decision Support lie in:

- Incorporation of real time input and analysis of streaming biosignals into a DSS
- Implementation of decision support in a distributed environment
- Implementation of decision support on a mobile platform
- Maintenance of consistency of knowledge and beliefs in the mobile distributed environment.

Initial work in this direction is reported in [11-13].

A final observation: a further contribution of our technology can be found in data aggregation to obtain stronger clinical evidence to support evidence-based best practice. Data routinely collected from telemonitoring will yield large collections of clinical data with the potential for data mining in order to produce more statistically powerful and accurate clinical evidence. Such data aggregation effort requires standards relating to representation of biosignal and other data and the associated metadata needed to compare and interpret them.

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